CHOICE AND TERMINAL-LINK RESPONSE TOPOGRAPHY

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Six pigeons responded under concurrent-chains schedules. For 3 birds, pecking was required in both initial links; for 3 others, treadle pressing was required. For all subjects, pecking was required in one terminal link and treadling in the other. The initial links consisted of independent variable-interval 60-s schedules. All birds were exposed to five pairs of terminal-link variable-interval schedules over 10 conditions: 6 s versus 54 s, 18 s versus 42 s, 30 s versus 30 s, 42 s versus 18 s, and 54 s versus 6 s. Comparisons of responding under nominally identical terminal-link variable-interval schedules showed that, without exception, higher choice proportions were obtained for the alternative correlated with terminal-link pecking. Moreover, terminal-link delay to reinforcement was shorter for terminal-link pecking than for terminal-link treadling chains. This factor, along with response force requirements, was implicated in explaining the present as well as previous findings of preference for pecking over treadling. It was found also that the delay-reduction hypothesis provided only a moderately accurate description of performance under concurrent chains in which different terminal-link response topographies are required. These findings suggest that quantitative models neglecting the effects of differing terminal-link topographies may be incomplete.

Key words: choice, delay-reduction hypothesis, response topography, concurrent-chains schedules, variable-interval schedules, key pecking, treadle press, pigeons

Chain schedules comprise two or more reinforcement schedules sequentially in effect, each correlated with a different stimulus. Responding in links prior to the terminal links is reinforced by a change from the stimulus correlated with that component schedule to the stimulus correlated with the following component schedule. Typically, unconditioned reinforcement is scheduled in the terminal link. The response topographies required in the various links may be topographically similar or dissimilar.

Three previous studies have reported differences in steady-state responding under chains with dissimilar terminal-link response topographies that are otherwise nominally identical (Lattal & Crawford-Godbey, 1985; Starin, 1987, 1988). For instance, Starin (1988), using a concurrent-chains procedure, found that irrespective of whether pecking or treadling was required in the initial links, more responses were allocated to the alternative re-

quiring terminal-link pecking than to the alternative requiring terminal-link treadling. Because pecking is emitted at a much higher rate than is treadling, the higher reinforcement rate associated with pecking may be the variable largely responsible for explaining the obtained preference towards that alternative. Relatedly, Fantino (1968) found choice to be affected by schedules requiring differing response rates, even when the overall rates of reinforcement were identical. Collectively, these findings suggest that current accounts of choice neglecting events taking place during the terminal links may be incomplete.

The delay-reduction hypothesis (e.g., Fantino, 1969, 1977, 1981; Squires & Fantino, 1971) is now, arguably, the preferred model for describing performance under concurrent-chains schedules, at least when variable-interval (VI) schedules are programmed in both the choice and outcome phases (Davison, 1987; Fantino & Davison, 1983). The delay-reduction hypothesis states that it is the reduction in time to unconditioned reinforcement correlated with the onset of a stimulus that gives that stimulus its conditioned reinforcing effectiveness. Choice, according to the delay-reduction hypothesis, may be described by the following equation (after Fantino & Davison, 1983):

These data were collected as part of a doctoral dissertation submitted to the faculty of The Graduate College at Western Michigan University. I am indebted to Jack Michael and Alan Poling for their helpful comments on an earlier version of this manuscript. Correspondence and reprint requests may be sent to Stephen Starin, Developmental Services Program Office, 401 N.W. 2nd Avenue, Suite S526, Miami, Florida 33128.

$$\frac{R_L}{R_L + R_R} = \frac{\sqrt{r_L}(T - t_{2L})}{\sqrt{r_L}(T - t_{2L}) + \sqrt{r_R}(T - t_{2R})}$$

(when $t_{2L} < T$, $t_{2R} < T$),

= 1 (when $t_{2L} < T$, $t_{2R} > T$),

= 0 (when $t_{2L} > T$, $t_{2R} < T$),

where R_L and R_R refer to the number of initial-link responses to the left and right alternatives, respectively, T is the average time to unconditioned reinforcement from the onset of the initial links, t_{2L} and t_{2R} refer to the average durations of the left and right terminal links, and r_L and r_R refer to the overall rates of unconditioned reinforcement for the left and right alternatives. Whenever t_{2L} or t_{2R} is greater than T , entry into that terminal link produces an increase in the average delay to reinforcement. Consequently, the delay-reduction hypothesis predicts that responding would be allocated exclusively to the other alternative (see Fantino, 1969, 1977, 1981, for detailed treatment).

Much recent research has focused on extending the delay-reduction hypothesis to novel areas including elicited responding (Fantino, 1982), foraging (Abarca & Fantino, 1982), observing (Case & Fantino, 1981), percentage reinforcement (Spetch & Dunn, 1987), self-control (Ito & Asaki, 1982; Navarick & Fantino, 1976), and three-alternative choice (Fantino & Dunn, 1983). Fantino and Davison (1983) state that, "Little has been done to further assess or refine [the delay-reduction hypothesis] in the area wherein it was developed: choice for VI schedules within the concurrent-chains framework" (p. 2). Virtually all of the studies exploring the generality of the delay-reduction hypothesis have done so using concurrent chains in which the same response topography is required in all links. Noticeably absent are studies investigating its applicability to concurrent chains requiring dissimilar terminal-link topographies. A major purpose of the present study, therefore, is to remedy this by examining how well the delay-reduction hypothesis describes choice under these circumstances. The generality of the delay-reduction hypothesis is further tested by requiring, during the choice phase, 3 subjects to depress a foot treadle, a response topography heretofore untested in the concurrent-chains procedure. Finally, the present study constitutes a systematic extension of previous work

investigating performance differences under chains with dissimilar terminal-link response topographies by exploring unequal as well as equal terminal-link reinforcement schedules. Because the ultimate goal of basic research is the prediction and control of human behavior and because human behavior is largely characterized by chains in which the topographies differ (Keller & Schoenfeld, 1950), the comparison of responding under both chain types may have both practical and theoretical implications.

METHOD

Subjects

Six barren-hen White Carneau pigeons maintained at 80% of their free-feeding body weights served as subjects. All subjects were housed individually with free access to water and grit in their home cages. Because all birds had previous histories responding under concurrent-chains procedures (Starin, 1988), no preliminary training was necessary. Birds 1, 2, and 3 were assigned to the initial-link pecking condition, and Birds 4, 5, and 6 were assigned to the initial-link treading condition.

Apparatus

Two experimental chambers measuring approximately 40 cm long, 40 cm deep, and 40 cm across were used. Each was equipped with two response keys and two foot treadles. The keys were centered 20 cm above the chamber floor, 7.5 cm apart. Each key could be illuminated in red, yellow, or green and required a minimum force of 0.2 N to be activated. Two aluminum foot treadles approximately 8 cm long and 2 cm wide were affixed to the response panel, 6 cm from either side wall. The treadles were sloped 30° from the vertical with the front edge of the treadles resting 3.5 cm above the chamber floor. A minimum force of approximately 1 N with an excursion of 2 mm was required to operate a microswitch. Treading stimuli consisted of 7.5-W red, white, and green lamps mounted behind a 1.5-cm translucent plastic panel above each treadle. The panels were 15 cm above the chamber floor and 4 cm from the side walls.

A 5-cm by 6-cm aperture centered in the response panel 7 cm from the floor allowed access to mixed grain. When operated, the hopper was illuminated with a 7.5-W white

lamp. A 7.5-W white lamp mounted in the center of the chamber ceiling provided general illumination. Ventilation and white masking noise were present throughout the experiment. Experimental contingencies and data recording were controlled by a Digital Equipment Corporation PDP-8e® minicomputer equipped with SuperSked® software and interfacing located in an adjacent room.

Procedure

During the choice phase subjects responded on two concurrently available keys or treadles. Two independent timers programmed entry into the mutually exclusive terminal links on a VI 60-s basis. Initial-link responses were reinforced occasionally by production of the stimulus associated with its corresponding terminal link. Upon entry into a terminal link, responses were effective only on the programmed key or treadle. All other manipulanda became inoperative and both initial-link timers were stopped. A 4-s food delivery in the terminal links was arranged under the programmed VI (see Table 1 for scheduled VI values). Immediately after reinforcement, the initial links were reinstated and the procedure repeated until 40 reinforcers had been delivered. All VI schedules consisted of a distribution of 10 interreinforcement intervals (IRIs) constructed according to a progression suggested by Catania and Reynolds (1968). The IRIs were presented to the subject in a random sequence.

For birds in the initial-link pecking condition, one chain required pecks to the same key in both links. The concurrently available chain required responses to the key and treadle on the opposite side of the chamber. For birds in the initial-link treadling condition, one chain required responses to the same treadle in both links. The opposing chain required responses to the treadle and key located on the opposite side of the chamber.

For all subjects, responses to any nonilluminated manipulandum in either link produced a 3-s blackout during which all timers were stopped and responses had no programmed consequences. For a given subject, the initial-link stimuli were always identical, whereas the terminal-link stimuli were different from both each other and from the initial-link stimuli. Table 1 presents stimulus configurations for each subject.

All subjects were exposed to five different pairs of terminal-link VIs (one VI for each terminal-link topography) while holding the initial-link VIs constant at 60 s. The programmed terminal-link VI pairs were 54 s versus 6 s, 42 s versus 18 s, 30 s versus 30 s, 18 s versus 42 s, and 6 s versus 54 s for the left and right alternatives, respectively. After responding had become stable under a particular pair of terminal-link VIs and response topographies, the terminal-link topographies were reversed and responding allowed to become stable under these conditions. Next, the topographies were reversed again and a new pair of terminal-link VIs arranged. This procedure continued until the subject had been exposed to each VI value on each key for each terminal-link response topography. This resulted in 10 conditions per subject. Table 1 shows the sequence of conditions and the number of sessions per condition for each subject. A change in conditions was initiated when the following criteria were met: (a) a minimum of 10 days per condition and (b) visual inspection revealed a minimum of 5 consecutive days with no increasing or decreasing trend in relative response rates.

The primary dependent variables were absolute and relative response rates to each alternative during the initial links. Absolute rate of responding was calculated by dividing the number of responses to a particular alternative by the total amount of time in the initial links. Relative response rates were calculated by dividing the number of initial-link responses to one alternative by the total number of initial-link responses to both alternatives. Initial-link time allocation was also measured. To measure time spent responding to a particular alternative during the initial links, a cumulative timer began with a response to that alternative and stopped with a response to the other alternative. Relative time allocation was calculated by dividing the cumulated time spent responding to one alternative by the total amount of time spent in the initial links.

RESULTS

Initial-Link Pecking Condition

Unless otherwise noted, all data presented are from the last 5 days of each condition averaged over two exposures to each condition.

Table 1

Summary of experimental conditions. Key pecking was required in the initial links of all conditions for S1, S2, and S3. Treadling was required in the initial links of all conditions for S4, S5, and S6. Key pecking and treadling were required in the opposing terminal links for all subjects and are denoted by K and T, respectively. Stimulus colors are also shown: R = red, Y = yellow, G = green, and W = white.

Subject	Condition	Terminal-link VI(s)	Terminal-link topography	Initial-link stimuli	Terminal-link stimuli	Total sessions
		Left/Right	Left/Right	Left/Right	Left/Right	
S1	1	6/54	K/T	R/R	Y/G	30
	2	6/54	T/K	R/R	G/Y	12
	3	18/42	K/T	R/R	Y/G	16
	4	18/42	T/K	R/R	G/Y	10
	5	54/6	K/T	R/R	Y/G	27
	6	54/6	T/K	R/R	G/Y	11
	7	42/18	K/T	R/R	Y/G	10
	8	42/18	T/K	R/R	G/Y	11
	9	30/30	K/T	R/R	Y/G	10
	10	30/30	T/K	R/R	G/Y	10
S2	1	6/54	K/T	Y/Y	G/R	19
	2	6/54	T/K	Y/Y	R/G	13
	3	18/42	K/T	Y/Y	G/R	10
	4	18/42	T/K	Y/Y	R/G	12
	5	42/18	K/T	Y/Y	G/R	13
	6	42/18	T/K	Y/Y	R/G	18
	7	54/6	K/T	Y/Y	G/R	16
	8	54/6	T/K	Y/Y	R/G	10
	9	30/30	K/T	Y/Y	G/R	15
	10	30/30	T/K	Y/Y	R/G	15
S3	1	6/54	K/T	G/G	R/W	23
	2	6/54	T/K	G/G	W/R	22
	3	18/42	K/T	G/G	R/W	16
	4	18/42	T/K	G/G	W/R	19
	5	42/18	K/T	G/G	R/W	12
	6	42/18	T/K	G/G	W/R	16
	7	54/6	K/T	G/G	R/W	21
	8	54/6	T/K	G/G	W/R	10
	9	30/30	K/T	G/G	R/W	15
	10	30/30	T/K	G/G	W/R	10
S4	1	54/6	K/T	W/W	R/G	12
	2	54/6	T/K	W/W	G/R	11
	3	42/18	K/T	W/W	R/G	11
	4	42/18	T/K	W/W	G/R	10
	5	18/42	K/T	W/W	R/G	10
	6	18/42	T/K	W/W	G/R	10
	7	6/54	K/T	W/W	R/G	10
	8	6/54	T/K	W/W	G/R	10
	9	30/30	K/T	W/W	R/G	10
	10	30/30	T/K	W/W	G/R	10
S5	1	54/6	K/T	W/W	R/G	23
	2	54/6	T/K	W/W	G/R	22
	3	42/18	K/T	W/W	R/G	16
	4	42/18	T/K	W/W	G/R	19
	5	18/42	K/T	W/W	R/G	12
	6	18/42	T/K	W/W	G/R	16
	7	6/54	K/T	W/W	R/G	21
	8	6/54	T/K	W/W	G/R	10
	9	30/30	K/T	W/W	R/G	15
	10	30/30	T/K	W/W	G/R	10

Table 1 (Continued)

Subject	Condition	Terminal-link VI(s)	Terminal-link topography	Initial-link stimuli	Terminal-link stimuli	Total sessions
		Left/Right	Left/Right	Left/Right	Left/Right	
S6	1	54/6	K/T	W/W	R/G	23
	2	54/6	T/K	W/W	G/R	22
	3	42/18	K/T	W/W	R/G	16
	4	42/18	T/K	W/W	G/R	19
	5	18/42	K/T	W/W	R/G	12
	6	18/42	T/K	W/W	G/R	16
	7	6/54	K/T	W/W	R/G	21
	8	6/54	T/K	W/W	G/R	10
	9	30/30	K/T	W/W	R/G	15
	10	30/30	T/K	W/W	G/R	10

Figure 1 shows, for each subject, initial-link pecking rates as a function of the arranged terminal-link VI. To facilitate comparison of responding under similar reinforcement schedules, the data are presented according to the programmed terminal-link VI, although, with the exception of VI 30-s schedules, the VIs shown on the abscissa could not be in effect at the same time. Without exception, subjects pecked faster to the chains requiring terminal-link pecking than to the nominally identical terminal-link treading chains. In general, subjects also showed an orderly decrease in initial-link response rates under both chain types as their terminal-link VIs increased. These data are presented in Table 2. The middle column presents the absolute initial-link pecking rates for all conditions, although not necessarily in the order in which they occurred (see Table 1 for condition order). As in Figure 1, these data show higher response rates in the initial links of chains requiring terminal-link pecking.

Predicted and obtained choice proportions for the initial-link pecking condition are also shown in Table 2. The delay-reduction hypothesis requires decreasing choice proportions as the mean terminal-link VI for that alternative increases. As predicted, all subjects showed this general response pattern. Specifically, for chains requiring terminal-link pecking, group choice proportions of .92, .86, .65, .49, and .35 were obtained for programmed VIs of 6 s, 18 s, 30 s, 42 s, and 54 s, respectively.

The upper half of Table 3 shows predicted and obtained choice proportions for terminal-link pecking and treading chains using both

response and time distribution. For instance, the first row of data for S1 shows that under conditions in which the delay-reduction hypothesis predicts a choice proportion of .92, obtained choice proportions for pecking and treading were .98 and .76, respectively, using response distribution. When time distribution is used, the choice proportions for pecking and treading were 1.00 and .52, respectively. In a given row, the obtained choice proportion for terminal-link pecking chains and for terminal-link treading chains come from different conditions. These data are presented together to facilitate comparisons of obtained response and time allocation at a given predicted value. Without exception, higher choice proportions were obtained for terminal-link pecking chains than for nominally identical terminal-link treading chains. Moreover, this finding obtained using both response and time allocation.

Since Baum (1974), it has become commonplace to use simple linear regression analysis to determine the best fitting (i.e., least squares) straight line between predicted and obtained values. Most often, regression procedures are used to find the best fitting line between the logarithms of response ratios and reinforcer ratios. Ratio logarithms were not used in the present case in order to allow for more meaningful comparisons between the present and previous concurrent-chains studies in which proportional measures were used. Although proportional measures have been criticized (Baum, 1979), Fantino and Davison (1983) suggest that problems associated with their use may be obviated by transforming the data through an inverse sine transformation

Table 2

Response rates and choice proportions for initial-link pecking birds. The required initial-link topography for all subjects was key pecking. The nominal reinforcement schedules were concurrent VI 60 s. All data represent the mean of the last 5 days of each condition. K = key peck, T = treadle press.

Subject	Terminal-link topography	Scheduled terminal-link VI(s)	Initial-link response rate	Terminal-link pecking	
	Left/Right	Left/Right	Left/Right	Predicted choice proportion	Obtained choice proportion
S1	K/T	6/54	53.28/0.30	.92	.99
	T/K	6/54	24.28/19.10	.08	.44
	K/T	18/42	54.52/9.77	.73	.85
	T/K	18/42	24.85/21.65	.27	.47
	K/T	30/30	20.21/33.27	.50	.38
	T/K	30/30	9.66/46.41	.50	.83
	K/T	42/18	13.96/39.68	.27	.26
	T/K	42/18	0.52/56.84	.73	.99
	K/T	54/6	2.41/52.60	.08	.04
S2	T/K	54/6	2.46/60.92	.92	.96
	K/T	6/54	73.47/0.38	.92	.99
	T/K	6/54	46.87/16.72	.08	.26
	K/T	18/42	74.19/4.27	.73	.95
	T/K	18/42	42.09/22.63	.27	.35
	K/T	30/30	50.45/12.37	.50	.80
	T/K	30/30	18.99/49.61	.50	.72
	K/T	42/18	42.33/15.68	.27	.73
	T/K	42/18	21.56/63.12	.73	.75
S3	K/T	54/6	27.40/31.43	.08	.47
	T/K	54/6	1.68/60.06	.92	.97
	K/T	6/54	64.77/1.96	.92	.97
	T/K	6/54	26.31/24.26	.08	.48
	K/T	18/42	60.41/8.15	.73	.88
	T/K	18/42	27.67/26.08	.27	.49
	K/T	30/30	30.03/22.37	.50	.57
	T/K	30/30	22.67/35.61	.50	.61
	K/T	42/18	33.30/18.47	.27	.64
	T/K	42/18	16.73/48.68	.73	.74
	K/T	54/6	22.37/32.95	.08	.40
	T/K	54/6	26.42/46.21	.92	.64

(arc sin function) prior to conducting the regression analysis.

In the present study, after predicted and obtained choice proportions had undergone inverse sine transformations, a linear regression analysis was carried out on the transformed data. Figure 2 presents the results of the linear regression analysis for each subject and for the group. The equation for the best fitting straight line and the correlation coefficient are shown on each panel. The slopes of the regression functions range from 0.53 to 1.12 for the individual subjects. The slope of the regression function for the group is 0.85. For all subjects,

the intercept is positive and ranges from 0.19 to 0.43 for the individual birds. For the group, the intercept is 0.30. Because the numerator of the proportion fraction contains values from the terminal-link pecking chains, these data show a strong bias towards the alternative requiring terminal-link pecking. The percentage of variability in the obtained values accounted for by the predicted values varies between 59% and 83% and is 72% for the group.

Initial-Link Treadling Condition

Figure 3 depicts initial-link treadling rates for all subjects. Subjects generally treadled

Fig. 1. Initial-link key-pecking rates as a function of the programmed terminal-link VI. Open squares represent rate of pecking in the initial links of chains requiring terminal-link pecking. Filled squares represent rates of pecking in the initial links of chains requiring terminal-link treadingling.

faster under chains requiring terminal-link pecking than terminal-link treadingling. The difference between the two chain types is, however, less than that obtained under initial-link pecking conditions. Absolute initial-link response rates are shown in Table 4. As in Figure 3, these data show that the birds generally

Table 3

Predicted versus obtained choice proportions. Obtained choice proportions represent the mean of the last 5 days of each of two similar conditions. Values in the obtained columns represent relative response or time allocation during the initial links.

Subject	Predicted choice proportion	Obtained response distribution (R)	Obtained time distribution (T)
		Pecking/Treadingling	Pecking/Treadingling
S1	.92	.98/.76	1.00/.52
	.73	.92/.63	.87/.53
	.50	.61/.39	.49/.10
	.27	.37/.08	.21/.00
	.08	.24/.02	.08/.02
S2	.92	.98/.63	1.00/.76
	.73	.85/.46	.96/.69
	.50	.76/.24	.85/.14
	.27	.54/.15	.72/.21
	.08	.37/.02	.34/.01
S3	.92	.81/.56	.99/.53
	.73	.81/.43	.94/.44
	.50	.59/.41	.61/.21
	.27	.57/.19	.64/.16
	.08	.44/.19	.31/.22
S4	.92	.74/.62	.89/.82
	.73	.64/.52	.75/.61
	.50	.57/.43	.62/.47
	.27	.48/.36	.62/.49
	.08	.38/.26	.60/.40
S5	.92	.78/.64	.82/.74
	.73	.72/.62	.80/.67
	.50	.53/.44	.65/.62
	.27	.38/.28	.37/.39
	.08	.36/.22	.48/.25
S6	.92	.81/.72	.78/.75
	.73	.73/.55	.64/.47
	.50	.60/.40	.57/.29
	.27	.45/.27	.39/.15
	.08	.28/.19	.22/.07

allocated more responses to the terminal-link pecking chains. Table 4 also indicates that all subjects showed decreasing choice proportions as the terminal-link VI for that alternative increased. Group choice proportions of .77, .69, .57, .43, and .34 were obtained for terminal-link VIs of 6 s, 18 s, 30 s, 42 s, and 54 s, respectively, on the terminal-link pecking chain.

The bottom half of Table 3 shows predicted choice proportions and obtained response and time allocation. In all cases, birds distributed more responses to the alternative requiring ter-

Fig. 2. Results of linear regression analysis for initial-link pecking conditions after the data had undergone an inverse sine transformation. Regression equation and correlation coefficient are shown for each subject and for the group.

minal-link pecking; with only one exception, birds allocated more time to the alternative requiring terminal-link pecking.

Figure 4 shows, for each subject and the group, the results of a linear regression on predicted and obtained choice proportions after each had undergone an inverse sine transformation. The slopes of the best fitting straight lines range from 0.41 to 0.54. The slope of the group regression function is 0.47. Response slopes range from 0.30 to 0.43 for individual subjects. For the group, the intercept is 0.37. These data indicate a systematic bias towards the alternative requiring terminal-link pecking. Finally, for individual subjects, the percentage of variability in obtained choice proportions accounted for by the predicted choice proportions varies between 46% and 92%. For the group, the coefficient of determination is approximately 58%.

DISCUSSION

In general, the present data show that absolute response rates and choice proportions were higher under terminal-link pecking chains than under terminal-link treadling chains. Furthermore, these results obtained for both initial-link pecking and treadling and held under a wide variety of terminal-link VIs. These data are consistent with two previous investigations. Starin (1988), using a concurrent-chains procedure, found higher response rates, and hence choice proportions, under terminal-link pecking chains than under terminal-link treadling chains although only one pair of terminal-link VIs (30 s vs. 30 s) was investigated. The present findings are also consistent with those of Lattal and Crawford-Godbey (1985) who obtained higher response rates under chains requiring pecking in both links than

under chains requiring pecking in the initial link and treadling in the terminal link. In their study, however, initial-link treadling was not investigated and a single-response procedure was employed. Such methodological differences between the Lattal and Crawford-Godbey (1985) study and the present study make it difficult to make strong comparisons between the two.

The present data are inconsistent with one earlier investigation. Starin (1987), using a single-response procedure, obtained higher response rates under all chains requiring the same topography in both links. Specifically, he found that chains requiring pecking in both links engendered higher response rates than did chains requiring pecking in the initial link and treadling in the terminal link. Likewise, higher response rates were obtained under chains requiring treadling in both links than under chains requiring treadling in the initial link and pecking in the terminal link. The reasons for the discrepancy between the findings of the present study and those of Starin (1987) are unclear, but it has been previously reported that "variables that seem irrelevant for the single key may have large effects when responding is reinforced concurrently on each of two keys" (Catania, 1963, p. 300). This may have been the case in the procedures of Starin (1987); a preference for pecking may have existed, but because of the single-response procedure, it was not apparent. The present data, along with those of Starin (1988), appear to substantiate an explanation based upon a preference for one particular response topography over another. Specifically, this hypothesis states that, other things being equal, birds will respond faster to the alternative requiring terminal-link pecking than to the alternative requiring terminal-link treadling.

Unfortunately, all was not equal in any of the previous studies in this area. All published studies investigating differences in performance between chains with dissimilar terminal-link topographies have one additional source of uncontrolled variability—differences in obtained terminal-link duration. All of these studies used reinforcement schedules that were nominally identical; however, the actual values of the schedules differed, sometimes quite significantly. For instance, in Starin (1988) the nominal VI in the terminal links was 30 s for both alternatives. The obtained VIs often dif-

Fig. 3. Initial-link treadling rates as a function of the programmed terminal-link VI. Open squares represent rate of treadling in the initial links of chains requiring terminal-link pecking. Filled squares represent rates of treadling in the initial links of chains requiring terminal-link treadling.

fered from these values. This in itself is not significant if the obtained VIs for both pecking and treadling differed from the programmed VIs by the same amount. However, they did not. The mean VI for pecking was always shorter than the mean VI for treadling. Often, under concurrent schedules, the obtained schedule parameters influence performance, not the programmed values (e.g., Baum, 1974;

Table 4

Response rates and choice proportions for initial-link treadling birds. The required initial-link topography for all subjects was treadle pressing. The nominal reinforcement schedules were concurrent VI 60 s. All data represent the mean of the last 5 days of each condition. K = key peck, T = treadle press.

Subject	Terminal-link topography	Scheduled terminal-link VI(s)	Initial-link response rate	Terminal-link pecking	
	Left/Right	Left/Right	Left/Right	Predicted choice proportion	Obtained choice proportion
S4	K/T	6/54	17.44/2.78	.92	.86
	T/K	6/54	19.57/5.87	.08	.23
	K/T	18/42	16.75/6.37	.73	.72
	T/K	18/42	18.99/7.86	.27	.29
	K/T	30/30	12.48/8.30	.50	.60
	T/K	30/30	10.83/12.02	.50	.53
	K/T	42/18	12.19/6.19	.27	.66
	T/K	42/18	9.34/11.39	.73	.55
	K/T	54/6	8.14/7.43	.08	.52
S5	T/K	54/6	4.91/7.99	.92	.62
	K/T	6/54	10.13/2.78	.92	.78
	T/K	6/54	7.04/3.50	.08	.33
	K/T	18/42	6.80/2.23	.73	.75
	T/K	18/42	6.81/4.91	.27	.42
	K/T	30/30	6.47/5.17	.50	.56
	T/K	30/30	8.10/8.30	.50	.51
	K/T	42/18	3.04/6.11	.27	.33
	T/K	42/18	3.06/6.73	.73	.69
S6	K/T	54/6	3.88/6.22	.08	.38
	T/K	54/6	2.47/8.12	.92	.77
	K/T	6/54	11.02/4.56	.92	.71
	T/K	6/54	11.92/5.05	.08	.30
	K/T	18/42	9.01/5.54	.73	.62
	T/K	18/42	11.21/8.63	.27	.43
	K/T	30/30	8.56/7.70	.50	.53
	T/K	30/30	6.20/12.32	.50	.67
	K/T	42/18	6.99/8.31	.27	.46
	T/K	42/18	2.80/13.71	.73	.83
	K/T	54/6	3.07/9.42	.08	.25
	T/K	54/6	1.69/14.50	.92	.90

Herrnstein, 1970; Shull & Pliskoff, 1967; but see Fantino & Dunn, 1983). Therefore, the obtained preference towards pecking may be an artifact of differences in reinforcement frequency.

Table 5 presents the programmed and obtained mean terminal-link VIs for each subject in the present study. As in previous studies, the average time to reinforcement after the onset of the terminal links was shorter for pecking than for treadling for all subjects.

Gross motor responses such as treadling require a greater amount of time to emit than

more discrete responses such as key pecking. Consequently, the rates of reinforcement for the two topographies may differ considerably. As it now stands, birds appear to prefer pecking over treadling; however, this has yet to be demonstrated independent of differences in terminal-link reinforcement frequency.

Three quantitative trends in the present data merit comment: the slopes of the regression lines, indicating sensitivity to the experimental contingencies; the intercept of the regression lines, indicating bias towards one alternative or the other; and, the coefficient of determi-

Fig. 4. Results of linear regression analysis for initial-link treadling conditions after the data had undergone an inverse sine transformation. Regression equation and correlation coefficient are shown for each subject and for the group.

nation, indicating the goodness of fit of the delay-reduction hypothesis in predicting performance. In the present study the response slopes obtained with subjects in the initial-link pecking condition are generally consistent with those found when pecking is required exclusively (Davison, 1987; Fantino & Davison, 1983). When treadling was the required initial-link topography, however, flatter response slopes were obtained. The reason for the differences between response slopes is unknown; however, Davison and Ferguson (1978) speculated that treadling may be less sensitive to reinforcement rate than is key pecking. Given that, in the present case, the only difference between the initial-link pecking condition and the initial-link treadling condition was the topography required and that considerable differences in response slopes resulted, the pres-

ent findings appear to substantiate the conclusions of Davison and Ferguson (1978). Further support for this notion is found by comparing the data in Figures 1 and 3. When pecking was required in the initial links, quite large differences were obtained between chains requiring dissimilar terminal-link response topographies. When treadling was the required initial-link topography, much smaller, and inconsistent, effects were obtained. These findings suggest that a given manipulation produces a smaller effect when birds depress a foot treadle than when they peck a key. The factors responsible for the relative insensitivity of treadling to reinforcement frequency remain to be determined, however.

A second aspect of interest in the present data is the regression function intercept. In this case, all intercepts were positive. Because

Table 5

Scheduled versus obtained terminal-link VIs. Obtained values represent the mean of the last 5 days of each of two similar conditions.

Subject	Scheduled terminal-link VI(s)	Obtained terminal-link VI(s)	Obtained terminal-link VI(s)
		Pecking	Treadling
S1	6	6	9
	18	18	20
	30	31	33
	42	44	46
S2	54	57	61
	6	7	26
	18	19	26
	30	32	44
S3	42	43	65
	54	56	69
	6	6	8
	18	19	21
S4	30	31	33
	42	43	45
	54	56	60
	6	7	9
S5	18	19	23
	30	31	33
	42	43	49
	54	55	59
S6	6	7	11
	18	20	21
	30	32	34
	42	46	47
S6	54	56	59
	6	7	11
	18	19	22
	30	31	34
S6	42	44	46
	54	58	61

topographies themselves engender different response rates. Thus, the bias towards pecking found in procedures using simple concurrent schedules is likely to be an artifact of the fact that key pecking can be emitted much faster than treadle pressing. In the present procedure, this problem was obviated by requiring the same response topographies in the initial links. Any obtained differences in the bias parameter cannot be due to the different rates inherent in the topographies but rather to a true preference for one topography over the other. The present results suggest that a strong preference for pecking over treadling exists even when the initial links are equated with respect to topography.

Several variables that may be responsible for bias have been suggested (e.g., Baum, 1974). The two most relevant to the present study are differences in response requirements and differences between scheduled and obtained reinforcement frequencies. Clearly, very dissimilar responses were required in the terminal links of the present study. One major difference between them is the amount of force required by each manipulandum. The key required a nominal value of 0.2 N whereas the treadle required approximately 1 N. This is a large difference and, quite likely, had a considerable effect on choice. Although the effects on choice of different force requirements have yet to be demonstrated empirically in concurrent-chains schedules, Chung (1965) and Hunter and Davison (1982) reported that response force affects choice behavior under simple concurrent schedules. Many of the variables found to affect choice under simple concurrent schedules have also been shown to affect choice under concurrent-chains schedules. Therefore, it is reasonable to assume, in the absence of conflicting data, that the differing response forces required in the terminal links of the present study had an effect on choice, producing a bias towards the alternative requiring the lesser effort.

Another factor implicated in producing bias is the difference between programmed and scheduled reinforcement rates. In the present study, terminal-link pecking chains were always associated with a shorter delay to reinforcement than were terminal-link treadling chains (see Table 5). It is plausible, therefore, that the obtained bias towards pecking is due,

pecking was placed in the numerator, this indicates a systematic bias towards terminal-link pecking. To date, no quantitative analyses of behavior under concurrent chains with different terminal-link responses have been conducted, but two studies have employed pecking and treadling in the opposing components of simple concurrent VI schedules (Davison & Ferguson, 1978; Wheatley & Engberg, 1978). Both studies found a systematic bias towards pecking over treadling when response measures were used; when time allocation was used smaller biases were obtained. Use of response measures when requiring responses of different topographies has one major drawback: The

to some extent, to the higher rate of reinforcement associated with this terminal-link topography. This possibility can be tested by considering a quantitative model employing obtained rather than scheduled delays to reinforcement and will be discussed below.

The final aspect of the present results of interest is the percentage of variability in the obtained data accounted for by the delay-reduction hypothesis. The present study obtained accounted-for variances that were somewhat smaller than in other studies employing concurrent chains (Davison, 1987; Fantino & Davison, 1983). This finding should not be surprising given that the delay-reduction hypothesis predicts performance solely on the basis of delays to reinforcement. The addition of differing response topographies adds another source of variability not taken into account by this model. If the effort associated with the two topographies is a major factor affecting choice (along with delay to reinforcement), its inclusion in a quantitative model should predict performance better than one based exclusively on time to reinforcement. Unfortunately, the development of such a model in the present case is impossible. The treadle required considerably different forces to operate depending upon where on the treadle the subject stepped. Casual observation showed that differences in where subjects stepped occurred frequently. Although it is reasonable to assume that response force affects choice in concurrent-chains schedules, without adequate quantification and calibration any attempt at modifying the delay-reduction hypothesis to incorporate response force would be premature.

When concurrent chains requiring different terminal-link topographies are arranged, the delay-reduction hypothesis provides only a moderately accurate description of the data. Although the exact reasons for this are unknown, there are two major variables that may be seen as causing trouble for the delay-reduction hypothesis: differences between scheduled and obtained reinforcement rates and differing amounts of force associated with pecking and treadling. It was noted above that concurrent-chains performance may be more sensitive to obtained reinforcement rates than to scheduled reinforcement rates. Moreover, the bias obtained may also be due to these differences. If so, replacing the scheduled values

with the obtained values in the delay-reduction hypothesis should produce a better description of the data. It should be noted at the outset that it is not being recommended that the delay-reduction hypothesis be modified to include obtained initial- and terminal-link durations. Indeed, one of its greatest strengths is its *a priori* predictive capabilities. Instead, it is merely suggested that one way to ascertain whether or not the present results were due to differences between scheduled and obtained reinforcement rates is by determining whether the use of obtained values offers any benefit over scheduled values. After replacing the scheduled values in the delay-reduction hypothesis with the obtained values, both sides of the equation underwent inverse sine transformations. A linear regression analysis was then carried out as before. The new regression equations for subjects in the initial-link pecking condition follow, with the previous equations shown in parentheses: $Y = 0.16 + 1.02x$ ($Y = 0.19 + 1.12x$) for S1, $Y = 0.27 + 0.84x$ ($Y = 0.34 + 0.90x$) for S2, $Y = 0.44 + 0.47x$ ($Y = 0.43 + 0.53x$) for S3, and $Y = 0.28 + 0.79x$ ($Y = 0.30 + 0.85x$) for the group. For birds in the treadling condition, the regression equations are: $Y = 0.33 + 0.46x$ ($Y = 0.38 + 0.41x$) for S4, $Y = 0.28 + 0.58x$ ($Y = 0.30 + 0.54x$) for S5, $Y = 0.26 + 0.62x$ ($Y = 0.43 + 0.48x$) for S6, and $Y = 0.29 + 0.55x$ ($Y = 0.37 + 0.47x$) for the group. With only one exception, the magnitude of bias is smaller using the obtained delays to reinforcement rather than the programmed delays, although the differences in bias between the two are generally quite small. This indicates that the shorter time to reinforcement associated with terminal-link pecking contributes to the obtained biases but only to a moderate degree. It is likely that differential efforts associated with the two topographies is another major contributor to bias. For 4 of 6 subjects, the response slopes were closer to matching using the obtained delays to reinforcement. This latter finding shows that initial-link performance is often, but not always, more sensitive to the obtained values than to the programmed values.

Although using obtained rather than scheduled times to reinforcement generally produced closer approximations to matching and less bias, these findings do not provide trouble for the delay-reduction hypothesis in analyzing

previous studies. In studies in which the terminal-link response topographies are similar, it can be expected that there would only be minimal deviations between scheduled and obtained values. Furthermore, the direction and degree of the deviations should be approximately equal for the two terminal links.

The percentages of variability accounted for by the revised and, in parentheses, the original delay-reduction hypothesis were 76% (81%), 67% (83%), 48% (59%), and 64% (72%) for S1, S2, S3, and birds in the pecking condition as a whole, respectively. For birds in the initial-link treadling condition, these values were 64% (50%), 86% (92%), 81% (46%), and 76% (58%) for S4, S5, S6, and the group. Overall, the use of obtained versus scheduled reinforcement delays had little impact on the amount of variability accounted for. In all cases, there remains a substantial amount of variability unaccounted for by time to reinforcement. Again, it is quite likely that the different force requirements associated with pecking and treadling contribute to some of the unaccounted-for variance.

The present findings suggest several potentially fruitful areas for further research. Response force and reinforcement frequency were confounded in the present study, as in previous investigations in this area. The exact contributions of each variable to choice between chains with different terminal-link response topographies should be addressed. A yoking procedure wherein reinforcement rates are equated would permit the relatively unambiguous assessment of choice between the two topographies. The systematic evaluation of the effects of response force on performance under concurrent-chains procedures should also be conducted. Response force has been demonstrated to affect choice in other circumstances, and further investigation within the concurrent-chains framework is warranted. The inclusion of these, and other, variables within the delay-reduction hypothesis would provide for a more complete account of behavior.

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Received September 15, 1988

Final acceptance November 29, 1988